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Heavy Flavor Production in CDF II Detector

Igor V. Gorelov[1]
(For the CDF Collaboration)

Department of Physics and Astronomy,
University of New Mexico,
800 Yale Blvd. NE, Albuquerque, NM 87131, USA
email:gorelov@fnal.gov

Abstract. For data collected with the CDF Run II detector, measurements of the charm and bottom production cross-sections are presented. The results are based both on large samples of fully reconstructed hadron decay products of charm and bottom made available by the tracking triggers and on a calorimeter jet triggered sample tagged by the presence of a secondary vertex. The experimental data are compared with theoretical predictions from recent next-to-leading order (NLO) QCD calculations.

The CDF Run I measurements [1] of the b-quark production cross-section compared with next-to-leading order (NLO) QCD theoretical predictions [2, 3] yielded a ratio $Data/Theory = 2.9 \pm 0.2(stat \oplus syst_{p_T}) \pm 0.4(syst_{fc})$ (see [1] for details). The apparent excess in the data over theoretical expectations had been established. The controversy has been subsequently re-examined by experimental and theoretical parties. The upgraded CDF and D0 detectors at the Tevatron entered the Run II data-taking period. A dramatic theoretical advance also occurred: a new theoretical technique was developed [3, 4, 5], which implemented a re-summation at the next-to-leading-log (NLL) level. The formalism was applied both to a fixed order perturbative calculation and to extraction of the non-perturbative part of the fragmentation function from previous experimental LEP data [6, 7]. As a result a $Data/Theory$ ratio (still for the CDF Run I data) was decreased from 2.9 to $1.7 \pm 0.5(exp) \pm 0.5(theory)$[1, 5].

The upgraded tracking of the CDF II detector provided an excellent opportunity for heavy-quark physics measurements. The fine track impact parameter (d_0) resolution of the CDF silicon tracker SVX-II made it possible to implement a new displaced track trigger selecting events with a pair of high p_T and large d_0 tracks. This trigger yielded a large data sample dominated by charm states decaying through hadron modes including $D^0 \to K^- \pi^+$, $D^+ \to K^- \pi^+ \pi^+$, and $D^{*+} \to D^0 \pi^+$ [2]. CDF has measured [8] the direct

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[2] Unless otherwise stated all references to the specific charge combination imply the charge conjugate combination as well.

production cross-sections of D-meson species. As both prompt and secondary (from b-quark decays) D-mesons contribute to the visible yield, the prompt fraction of the signals was extracted by fitting the shape of the impact parameter distribution for each particular hadron mode. The experimental results shown at Figure 1 have been compared with fixed order NLL (FONLL) calculations made for the charm sector [9]. The agreement seems to be moderate, with data lying at the upper bound of the theoretical uncertainties.

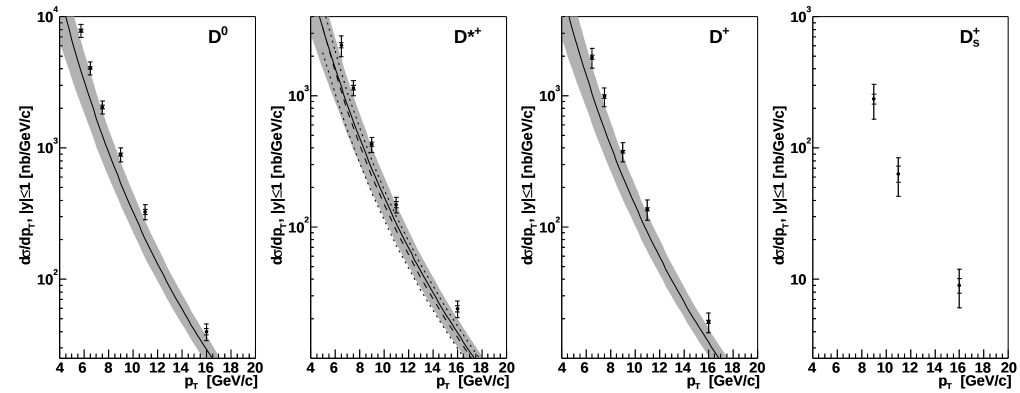

FIGURE 1. The differential D^0, D^+, D^{*+} and D_s^+ cross-section distributions measured [8] with the CDF II detector. The theoretical predictions are shown as a shaded band.

Another tracker-based trigger exploits the CDF central tracking chamber, for which reconstructed tracks are matched with hits in the muon chambers. At the highest Level-3 trigger a pair of muon candidates having opposite charge is reconstructed, and only pairs with an invariant mass $M(\mu^+\mu^-) \in [2.7, 4.0]\,\mathrm{GeV}/c^2$ around the mass of the J/ψ are accepted. This large triggered data sample of J/ψ mesons is used to measure the inclusive cross-section for b-hadrons, $H_b \to J/\psi X$. The J/ψ from the decay of H_b is likely to be displaced from the primary vertex where b-hadrons are assumed to be produced. The maximum likelihood fit of the pseudo-proper time $c\tau = L_{xy} \cdot (M/p_T)$ in bins of p_T (J/ψ) finds the b-fraction f_b of J/ψ yield in every p_T bin. The measured [10] differential b-hadron cross-section spectrum is shown in Figure 2 where it is compared with FONLL calculations [11]. The integrated total cross-section was found to be $\sigma(p\overline{p} \to H_b, H_b \to J/\psi, p_T(J/\psi) > 1.25\,\mathrm{GeV}/c, |y(J/\psi)| < 0.6) = 0.330 \pm 0.005(stat)^{+0.036}_{-0.033}(syst)\,\mu$b.

Heavy quark jets are good observables as their experimental energy spectra do not depend on knowledge of heavy-quark fragmentation functions, contrary to the cases discussed above. The systematics due to decay properties of heavy hadrons are reduced as well. The predictions of NLO models are expected to be more precise and less sensitive as collinear gluons causing large log-s are counted in jet cones. The CDF II b-jet cross section measurements are made with a $\sim 300\,\mathrm{pb}^{-1}$ data sample triggered by inclusive jet triggers based on the CDF II calorimeters. The b-jet production study extends the p_T reach beyond the [1.25, 25] GeV/c range accessible with final heavy hadron modes. The central jets of rapidity range $|Y_{jet}| < 0.7$ are reconstructed in Y-ϕ space using a cone-based iterative MidPoint algorithm [12] with a cone radius $R_{cone} = 0.7$. The hadronic energy scale of the jets is corrected and unfolded to the hadron particle level using Monte Carlo (MC) data samples. Additional correction is applied for ambient energy flow into the jet cone due to the underlying event. As b-quark decay

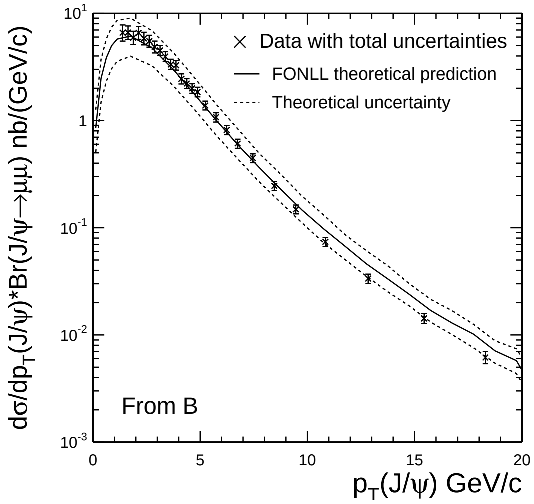

FIGURE 2. The differential cross-section for $p\overline{p} \rightarrow H_b X, H_b \rightarrow J/\psi X$, and $J/\psi \rightarrow \mu^+\mu^-$ with $|y(J/\psi)|<0.6$ and $p_T\ (J/\psi)>1.25\,\mathrm{GeV}/c$. The theoretical predictions are outlined in [11]. The central theoretical values underestimate the data points below $\sim 7.5\,\mathrm{GeV}/c$ and overestimate the ones above $\sim 7.5\,\mathrm{GeV}/c$.

products within the jet cone are also likely to be displaced from the primary vertex, reconstructed tracks are matched with the jet cone and required to have a displaced impact parameter d_0. Furthermore these tracks are fitted to a common secondary vertex, and the corresponding secondary vertex decay length is required to be significantly above zero, $L_{xy}/\sigma_{L_{xy}} > 3.0$. The jet satisfying these conditions is positively tagged as b-jet candidate. The tagged jet is likely to contain a decay vertex of b-, -¸ or light quarks (e.g. s- quark). Hence again the b-fraction f_b must be extracted. A fit of the reconstructed secondary vertex invariant mass distribution to MC templates of b- and non-b components of positively tagged jets finds an f_b for tagged jets in every p_T bin. The comparison of CDF II preliminary b-jet cross-section measurements to NLO predictions by S. Frixione *et al.* (see e.g. [13]) with parton distribution function (PDF) of version CTEQ6M is shown in Figure 3. The statistical and systematic errors on the last bins are dominated by the error on the b-tagged jets fraction. One of the main systematic error contributions comes from the jet energy scale.

In conclusion, CDF II has measured inclusive production cross-sections in the central rapidity region at $\sqrt{s} = 1960\,\mathrm{GeV}$ for D-mesons in exclusive decay modes with $p_T(D) > 5.5\,\mathrm{GeV}/c$, for b-hadrons in decay modes containing J/ψ in a p_T range of ~ 0 to $20\,\mathrm{GeV}/c$. The data and some recent theoretical calculations show reasonable agreement within experimental and theoretical uncertainties. CDF II has presented preliminary results on central production of b-tagged jets in a wide range, from 38 to $360\,\mathrm{GeV}/c$. The measurements are also in agreement with the most recent NLO predictions given theoretical and experimental uncertainties.

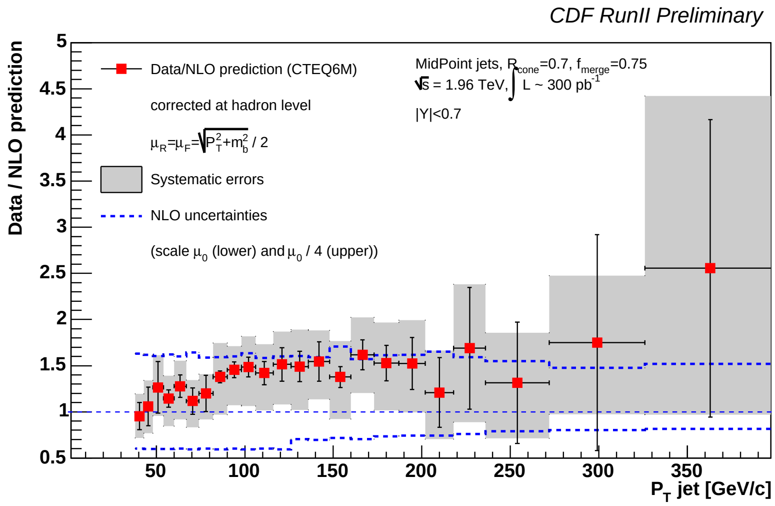

FIGURE 3. The comparison of *b*-jet cross-section measurements with NLO predictions by S. Frixione *et al.* made at the hadron level.

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REFERENCES

1. D. Acosta *et al.* (CDF Collab.), Phys. Rev. D **65**, 052005 (2002), [hep-ph/0111359].
2. P. Nason *et al.*, Nucl. Phys. **B327**, 49 (1989), erratum *ibid.* **B335**, 260 (1990); W. Beeneker *et al.*, Nucl. Phys. **B351**, 505 (1991).
3. S. Frixione, M. Mangano, P. Nason, and G. Ridolfi, “Heavy Flavors II”, eds. A.J. Buras and M. Lindner, Adv. Ser. Direct. High Energy Phys. **15**, 609-706 (1998), World Scientific Publishing Co., Singapore, 1998, [hep-ph/9702287].
4. M. Cacciari, M. Greco, P. Nason, JHEP **9805**, 007 (1998), [hep-ph/9803400].
5. M. Cacciari, P. Nason, Phys. Rev. Lett. **89**, 122003 (2002), [hep-ph/0204025].
6. A. Heister *et al.* (ALEPH Collab.), Phys. Lett. B **512**, 30 (2001); K. Abe *et al.* (SLD), Phys. Rev. D **65**, 092006 (2002) [Erratum-ibid. D**66** (2002) 079905].
7. R. Barate *et al.* (ALEPH Collab.), Eur. Phys. Jour. C **16**, 597 (2000), [hep-ex/9909032].
8. D. Acosta *et al.* (CDF Collab.), Phys. Rev. Lett. **91**, 241804 (2003), [hep-ex/0307080].
9. M. Cacciari, P. Nason, JHEP **0309**, 006 (2003), [hep-ph/0306212].
10. D. Acosta *et al.* (CDF Collab.), Phys. Rev. D **71**, 032001 (2005), [hep-ex/0412071].
11. M. Cacciari, S. Frixone, M. L. Mangano, P. Nason and G. Ridolfi, JHEP **0407**, 033 (2004), [hep-ph/0312132].
12. Gerald C. Blazey *et al.*, Run II Jet Physics: Proceedings of the Run II QCD and Weak Boson Physics Workshop, hep-ex/0005012; P. Aurenche *et al.*, The QCD and Standard Model Working Group: Summary Report from Les Houches, hep-ph/0005114.
13. S. Frixione, M.L. Mangano, Nucl. Phys. B **483**, 321 (1997), [hep-ph/9605270].